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Research supported by grants AFOSR-87-0249 and AFOSR-87-0249A has emphasized algebraic systems theory and the identification of systems from noisy data. Identification, which is based on mathematical (primarily algebraic) ideas has been the area of our main effort. Much work at the Center has been in preparation of reanalyses of published data and exposition of new methods of analysis of noisy data.

Research on basic aspects of algebraic system theory has also been active. This research contributes to the study of identification, because it is concerned with deep results about system properties in the exact, that is, noise-free case.

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June 30, 1988

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Re: Final report for AFOSR grant nos. 87-0249 and 87-0249A

Dear Maj. Crowley:

Enclosed is a copy of the final report for the above grants.
Copies of the papers referenced in the report have been included
for your convenience.

Please contact me if I can be of any further assistance.

Sincerely yours,

Mary Anna Garmon

Mary Anna Garmon
Associate Director

cc:

Marilyn Gordon
Grants Specialist I

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**Mathematical Techniques for
System Realization and Identification**

Final Report

June 1988

**R. E. Kalman
Principal Investigator**

July 1, 1987 through April 30, 1988

**U. S. Air Force Office of Scientific Research
Grant Number AFOSR-87-0249
and AFOSR-87-0249 A**

**Center for Mathematical System Theory
University of Florida**

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FORCE POSITION, POLICY, OR DECISION, UNLESS SO DESIGNATED BY OTHER DOCU-
MENTATION.

Research Summary

Research supported in the past few years under this grant at the CENTER FOR MATHEMATICAL SYSTEM THEORY has emphasized two broad areas:

- (i) Algebraic system theory.
- (ii) Identification of systems from noisy data.

The two topics are related to each other; indeed the new research on identification is based on mathematical (primarily algebraic) ideas and techniques rather than the traditional aproach via probability theory and statistics. During the period reported here, the second topic (studied mainly by the Principal Investigator and visitors) has been the area of main effort.

There is now a large body of new knowledge of identification, both as regards the general strategy of research and many specific results and techniques. In particular, a very careful and in-depth analysis of traditional techniques of statistics such as least squares (regression), principal components, and factor analysis, has shown that these techniques are irreversibly "flawed" because they allow too much role for "prejudices" (usually manifested as guesses at the nature of noise), rather than letting the data "speak for itself".

There has been practically no progress in the methodology of identification in the past forty years. As has been argued in KALMAN [1988], it is ab-

olutely necessary to eliminate preconceptions (technically, the prejudices) from the field, not only in order to make progress, but even to assess the limitations and applicability of present methods.

A large amount of work has been done at the Center in the preparation of reanalyses of published real data and the exposition of the new (algebraic, rather than probabilities) methods of analysis of noisy data. A research monograph is in preparation (KALMAN [1989]), as well as at least four additional mathematical papers, some of which have been already presented at high-level research conferences.

Research on basic aspects of algebraic system theory has also been active. (This research contributes indirectly to the study of identification, because it is concerned with deep results about system properties in the exact, that is, noise-free case. Evidently, noise-free identification must be well-understood before one attempts to study the noisy case). In particular, BIRGET [1986-1987] has continued the study of discrete-time, discrete-state systems (automata) from the algebraic point of view; BIRGET's research reported in these papers originated during his postdoctoral tenure (until 1985) at the Center.

EMRE (Postdoctoral fellow in 1986) also continues his work on realization (i.e., noise-free identification) theory with collaborators at the University of Texas at Lubbock. A previous postdoctoral (in the early 1980's) and now a permanent Center member, HAMMER [1987-88] has been very active in research on the algebraic theory of nonlinear systems since rejoining the Center in the summer of 1987.

The research of the Principal Investigator has important implications on the highly controversial debate concerned with the interpretation of quantum mechanics as a physical (i.e., "identifiable") theory. While this is by no means the main thrust of the investigation by the Principal Investigator, he has benefited from a research visit by ACCARDI [1988]. ACCARDI's work (University of Rome, ITALY) on the probabilistics of quantum mechanics began completely independently of the research under the grant but appears to be converging toward it, both in the kind of problems treated and in the mathematical methodology.

PUBLICATIONS SUPPORTED IN PART BY THE GRANT

L. ACCARDI

- [1988] "The harmonic oscillator as quantum central limit Bernoulli process", 29 pages, accepted by Probability Theory and its Applications.

J. C. BIRGET

- [1986a] "Stability and j-depth of expansions", July 1986, accepted by the Bulletin of Australian Mathematical Society.
- [1986b] "The synthesis theorem for finite regular semi-groups, and its generalization", 115 pages, accepted by the Journal of Pure and Applied Algebra.
- [1987a] "Concatenation of inputs in a two-way automaton", June 1987 24 pages, submitted to Theoretical Computer Science.
- [1987b] "Two-way automaton computations", 34 pages, submitted to RAIRO, Informatique Theorique.

E. EMRE and J. H. SEO

- [1987a] "A realization theoretic solution of two analytic matrix equations with application to stabilization of infinite dimensional systems", November 1986, 20 pages, to appear in the Proceedings of the International Symposium of Mathematical Theory Networks and Systems, Arizona, 1987.
- [1987b] "A realization theoretic solution of two analytic matrix equations with application to stabilization of infinite dimensional systems", 33 pages, submitted to IEEE Transactions on Automatic Control.
- [1987c] "Transfer matrices, polynomial fractions and realization of continuous-time linear time-varying systems", 10 pages, Proceedings of the Allerton Conference, October 1987.

E. EMRE, H. TAI, and J. H. SEO

- [1987] "Stabilization of continuous-time linear time-varying systems via transfer matrices and fractional

representations, to appear in the Proceedings of the American Control Conference, 37 pages, June 1988.
[Previous title: Transfer matrices, realization and control of continuous-time linear time-varying systems via polynomial fractional representations]

J. HAMMER

- [1987] "Assignment of dynamics for nonlinear recursive feedback systems", August 1987, 41 pages, to appear in the International Journal of Control.
- [1988a] "Fraction representations and robust stabilization of nonlinear systems", April 1988, 27 pages, to appear in Proceedings of the Nonlinear Control Conference, Nantes, France, Springer-Verlag.
- [1988b] "On robust stabilization of nonlinear systems", March 1988, 39 pages, accepted for publication in International Journal of Control.

R. E. KALMAN

- [1987] "The problem of prejudice in scientific modeling", in RECENT ADVANCES IN COMMUNICATION AND CONTROL THEORY, edited by R. E. Kalman, G. I. Marchuk, A. E. Ruberti, and A. J. Viberti, Optimization Software, Inc., 1987, pages 448-461. (LC Card No. 87-18604)
- [1989] IDENTIFICATION (research monograph), Springer, to appear in 1989.

PERSONNEL SUPPORTED UNDER THE GRANT

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Dr. R. E. Kalman, Principal Investigator, Departments of
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* Dr. G. Basile, Professor, Department of Electrical Engineering,
University of Florida, Gainesville, FL

* Dr. M. Fried, Professor, Department of Electrical Engineering,
University of Florida, Gainesville, FL

(b) Visitors

Short-term visitors for 1985/87

Dr. R. Hermann, Brookline, MA

Dr. P. Huber, Harvard University, Cambridge, MA

Dr. A. Lindenmayer, University of Utrecht, THE NETHERLANDS

Dr. J. Rissanen, IBM Almaden Research Center, San Jose, CA

Dr. Y. Rouchaleau, Ecole Nationale Supérieure des Mines de Paris,
FRANCE

Dr. R. Swan, University of Chicago, Chicago, IL

Dr. J. Waldvogel, University of South Florida, Tampa, FL

Dr. Y. Yamamoto, Kyoto University, JAPAN

* Courtesy affiliation only; no direct grant support.

Long-term visitors for 1985/87 (one month or more)

Dr. L. Accardi, Università Roma II, ITALY

Dr. L. Baratchart, I.N.R.I.A., Valbonne, FRANCE

Dr. J.-C. Birget, (now on faculty of University of Nebraska)

Dr. E. Eare, (now on faculty of Texas Technical University)

Dr. U. Oberst, University of Innsbruck, AUSTRIA